What is Radioactive Decay?

Professional Personnel

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RADIOACTIVE DECAY

The atomic structure for certain isotopes of elements is unstable. Radioactivity is the natural and spontaneous process by which the unstable atoms of an isotope of an element transform or decay to a different state, and emit or radiate excess energy in the form of particles or waves called radiation. These emissions are energetic enough to ionize atoms and are called ionizing radiation. Depending on how the nucleus releases this excess energy, either a lower energy atom of the same form results or a completely different nucleus and atom are formed.

The unstable atoms of a radioactive substance decay in a random fashion but at a characteristic rate. The length of time this takes, the number of steps required and the kinds of radiation released at each step are well known and are unique to that isotope. For instance, an atom of phosphorus-32 decays to an atom of non-radioactive sulfur-32, accompanied by the emission of a beta particle (electron) with an energy up to 1.71 million electron-volts (MeV).

DECAY

Most nuclear decays occur spontaneously and randomly, where a given fraction of atoms decay in a known given time period, independent of the number of atoms present.

The change, due to decay, in the number of atoms, ***dN***, during the time period, ***dt***, is expressed as:

$$-\frac{dN}{dt} = lN$$

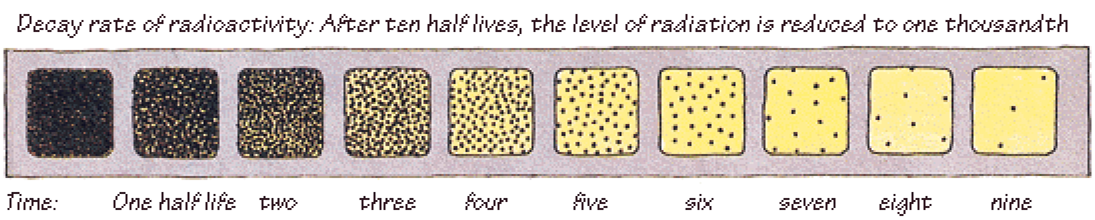
This equation can be solved to form the following equation:

$$N(t) = N_0 e^{-lt}$$

Where the number of atoms remaining (those that have not decayed) during a time period ***t*** is ***N(t)***, the original number of atoms present at the start of the time period is $\boldsymbol{N_0}$, and l is a proportionality constant known as the decay constant that equals 0.693/ $\boldsymbol{t_{½}}$. The base of natural logarithm is ***e*** and ***e*** equals 2.718.

HALF-LIFE ($\boldsymbol{t_{½}}$)

The half-life is the time required for a given amount of radioactive material to decrease by one half. After one half-life the amount of radioactive material is halved, after two half-lives it is reduced to one quarter, after three half-lives to one-eighth and so on.



The activity of any radionuclide is reduced to less than 1% after 7 half-lives.

This half-life is a time that is unique time to each radioisotope of an element. Half-lives can range from less than a millionth of a second to millions of years. The half-life can be mathematically expressed as the point in time when ***N(t)*** is one half of $\boldsymbol{N_0}$.

Replacing this expression in the above equation, where $\boldsymbol{t_{1/2}}$ is the half-life, gives:

$$1/2 = e^{-l\, t_{1/2}}$$

Taking the logarithm of both sides of the above equation and solving for the half-life $\boldsymbol{t_{1/2}}$ gives:

$$t_{1/2} = \frac{\ln(2)}{l}$$

ACTIVITY

The quantity of radioactive material present is generally measured in terms of activity rather than number of atoms or mass. Activity is a measurement of the number of radioactive decays or disintegrations an amount of material undergoes in a given period of time. Activity is related to mass, however, because the greater the mass of radioactive material, the more atoms are present to undergo radioactive decay.

Activity, ***A***, is expressed as:

$$A = lN(t)$$

The two most common units of activity are the Curie (conventional units) or the Becquerel (international units).

- 1 Curie (Ci) = 3.7 x10^{10} disintegrations per second (dps)
- 1 Becquerel (Bq) = 1 disintegration per second (dps)
- 1 Millicurie (mCi) = 1/1,000 (one thousandth) of a curie = 3.7 x 10^7 Bq
- 1 Microcurie (µCi) = 1/1,000,000 (one millionth) of a curie = 3.7 x 10^4 Bq

Working problems with exponential decays are good practice for many other fields. Exponential growth and decay are common concepts in biology, economics, and other sciences.

The US Santa Cruz website has an on-line activity calculator that will allow you to determine what the activity of a radionuclide is after a period of time:

http://ehs.ucsc.edu/Lab_Research_Safety/ehs.asp?page=Pubs/Ram/decay

Sources

Princeton University, http://www.princeton.edu/~ehs/radtrain/Modules/basics.html
Michigan State University,
http://www.pa.msu.edu/courses/1997spring/PHY232/lectures/radioactive/halflife.html